STEREOLITHOGRAPHIC METHOD AND APPARATUS FOR FORMING THREE-DIMENSIONAL STRUCTURE

BACKGROUND OF THE INVENTION

[0001] Stereolithographic techniques for forming three dimensional polymer structures are know. However, these techniques are primarily directed to layer by layer hardening of a polymeric material using laser irradiation and are not applicable to the production of metallic items/structures which have complex shapes having overhangs/undercuts that require the interposition of supporting arrangements such as scaffolds. Therefore, the need for a technique which enables a metallic three-dimensional structure having a complex shape, to be developed in this layer-by-layer manner, exists.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Fig. 1 is a schematic elevation showing the concept upon which a first embodiment of the invention is based.

[0003] Fig. 2 is a schematic view showing the manner in which droplets of two different liquefied/molten materials can be layered together in accordance with a second embodiment of the invention.

[0004] Fig. 3 is a schematic view of the arrangement shown in Fig. 2 following heat treatment wherein the solidified droplets of the outer material have been induced to soften, flow and to fill the voids between the droplets of the other material.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0005] Fig. 1 schematically depicts an embodiment of the invention. In this arrangement, an ejector 100 is supported over a bath or vat 102. The ejector 100 is operatively connected with a device 104 which scans the ejector back and forth along two mutually opposed axes. This scanning device 102 is operatively connected with a computer or the like type of NC controller 106 which also controls the ejection timing of the ejector 100.

[0006] Examples of ejectors of the type which are adaptable for use in this embodiment can be found in United States Patent No. 6,076,723 issued on June 20, 2000 in the name of Alfred I-Tsung Pan; and United States Patent No. 5,779,971 issued on July 14, 1998 in the name of I-Tsung Pan et al.

[0007] By ejecting droplets of liquefied/molten material from the ejector 100 over a predetermined pattern area it is possible to build a three-dimensional structure 200 layer-by-layer.

[0008] In order to ensure accurate formation of the three-dimensional structure, the ejector is maintained at essentially the same distance from the upper layer of the structure 200. This distance can be maintained by either moving (i.e. raising and lowering) the vat 102 with respect to the ejector or moving the ejector 100 with respect to the vat. Inasmuch as this technique is not dissimilar to inkjet printing, the ejector nozzle is maintained about 1-3 mm (by way of example only) from the upper layer in order to maximize the accuracy with which the three-dimensional structure is formed.

[0009] However, with the development of a number of layers which result in a structure that has overhang or extends upwardly at an angle, it becomes

necessary to support the structure, at least temporarily, against the force of gravity. In this embodiment this support is provided by a highly viscous liquid 110 which is supplied into the vat. The viscous liquid can be any suitable material such as a suitable silicone oil, glycol or a mixture waxes, molten metal or the like, that is highly viscous at room temperature. It is, however, necessary that the support liquid/material is not detrimentally reactive with the ejection material.

[0010] As will be noted from Fig. 1, the viscous or support liquid not only provides lateral support but can actually function as a horizontal foundation on which droplets of liquefied/molten material can be ejected and allowed to solidify. For example, a suspended layer 202 can be formed without the use of a scaffold by selecting the characteristics of the viscous liquid to be such as to resist softening or deformation sufficiently long for the initial layers of liquefied/molten droplets solidify and become sufficient rigid as to be able to support the following layers.

[0011] In accordance with this requirement, a supply of viscous liquid 108 is arranged to controllably supply viscous liquid into the vat under the control of a sensor 112. This sensor 112 is shown schematically connected to the injector 100. However, the apparatus according to this embodiment is not limited to this arrangement and suitable disposition of the sensor 112 can be used. This sensor 112 can comprise, by way of example, a range finder which can detect the level of the viscous liquid in the vat 102 and control it with respect to the level of the three-dimensional structure that is built up layer-by-layer by selective injection of droplets of liquefied/molten material from the ejector 100. Using a multi-target range finder enables both the liquid of the viscous liquid with respect to the level of the upper layer of the three-dimensional structure 200 which is being created, to be determined and the appropriate information provided to the

NC controller 106. This input can, of course, also be used to control the distance between the injector nozzle and the upper layer of the three-dimensional structure 200.

[0012] Figs. 2 and 3 schematically depict a structure which can be produced in accordance with a second embodiment of the invention. This embodiment is directed to a situation which can occur when the droplets of the liquefied/molten material solidify without completely blending/fusing into a unitary solid with the immediately adjacent material. This, as depicted in Fig. 2, while producing a structurally sound structure is such as to be porous and include small voids 210 between the almost completely interfused droplets. The voids that are located on the external surface results in a product which has a rough exterior.

[0013] In the event that this void inclusive structure is undesirable, the second embodiment of the invention uses two different materials to construct the three-dimensional structure. The first material is used to construct what shall be referred to as the "core" 212 of the structure while the second material is used to construct the outer "peripheral" layer 214 portions of the structure. This is carried out using multiple ejectors which respectively eject the first and second materials in liquefied/molten form.

[0014] In this particular embodiment, the first and second materials are respectively different metals having different melting points. For example, silver solder and tin solder can be used as the first and second materials respectively, inasmuch as the melting points of these materials a sufficiently different.

[0015] As each layer of the structure is developed, the ejector that ejects the second material which has a melting point lower than the first material, is scanned and energized in a manner that results in a structure which is exemplified in Fig. 2.

[0016] By heat treating the structure which is shown in Fig. 2, it is possible to induce the second lower melting point material to soften and flow into the voids and recesses which tend to be left between the solidified droplets of the first material in the manner illustrated in Fig. 3 without inducing any heat related deformation of the primary or core structure formed of the solidified droplets of the first material.

[0017] This results in a smooth outer surface and an attractive finished structurally stronger product.

[0018] It is further possible that further controlled heat treatment can be used to induce inter-infusion of the second material into the first and thus induce alloying to take place.

[0019] The materials which are used in the above mentioned embodiments are only limited by the temperatures which the components of the ejector can tolerate and the capacity of the viscous support liquid to tolerate the thermal loads which are imparted by the ejection of the liquefied/molten materials.

[0020] While this example of the second embodiment has involved the use of first and second metals, it is possible that mixtures of metals and non-metals be used. For example, a core of thermoplastic resin could used with copper as the second material. A metal plated plastic structure results. Apart from the aesthetic value of such a structure the body would also tend to become electrically conductive due to the permeation of the metal into the spaces between the hardened drops of resin and thus essentially throughout the structure.

[0021] A mixture of non-metals is also possible such as a combination of a thermoplastic resin and a UV setting resin. The core structure could be formed of the UV setting resin wherein each scan of the injector could be followed by the

scan of a source of UV radiation. The thermoplastic resin could be ejected to form the outer peripheral portions of the structure and subsequently subjected to heat treatment which would soften the resin and allow it to flow into the porous structure formed by the UV setting resin, and thus lead to the formation of the structure such as that depicted in Fig. 3.

[0022] The above-mentioned heat treatment of the thermoplastic resin is carried out after the structure has been removed from the vat and/or the viscous liquid drained off or otherwise removed. That is to say, the viscous/support liquid could extend to materials that set and are soluble in a suitable solvent and thus can be washed off or dissolved. These materials can be soluble in either polar or non polar solvents (e.g. water, methanol, ethanol, methyethylketone, chloroform etc.).

[0023] A further embodiment of the invention makes use of the viscous support liquid as the second material. By using a suitable resin as the support liquid, the void filled structure which results from the imperfect interfusing of the droplets of liquefied/molten material, can be arranged to fill with the support liquid per se. After being removed from the vat and excess liquid being removed either by draining or some other process such as warming, rinsing or the like, the resin or other material which has impregnated into the structure and which remains retained within the voids via surface tension/capillary effects (for example only) can be permitted to remain unchanged or can alternatively, be induced to undergo a change such as polymerization (for example) in response to an external stimulus or stimuli.

[0024] It should be noted that the term liquefied is intended to include materials which are liquefied via an increase in temperature in addition to those which are dissolved and/or liquefied by other means. Thus, the expression liquefied/molten includes molten metals and other materials which are one of

fluidized, dissolved or suspended in a carrier and thus in a condition wherein they can be ejected using a suitable ejection device which does not necessarily require the injection material to be electrically conductive.

[0025] Even though the present invention has been described with reference to only a limited number of embodiments, it will be understood that, given the preceding disclosure and the concepts which flow therefrom, a person of skill in the art of stereolithographics or the like type of fabrication techniques would be able to develop various modifications and variants of the disclosed techniques without the need of undue experimentation. It will be further understood that the scope of the invention is not limited to the specific arrangements which have been disclosed and that the scope of the invention is limited only by the appended claims.